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Book of abstracts

ACTUAL PROBLEMS OF RENEWABLE ENERGY, CONSTRUCTION AND ENVIRONMENTAL ENGINEERING

The time and place of the meeting: 3 – 5 June 2021
Faculty of Environmental, Geomatic and Energy Engineering,
Kielce University of Technology, Poland
al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce

Conference Chairs:

Anatoliy Pavlenko
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PERSPECTIVES OF USING MICROWAVE HEATING OF PETROLEUM PRODUCTS IN THE TANK

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The developed microwave heating technologies are characterized by high intensity and efficiency. These advantages make it possible to use microwave heating when drying food products, reducing the viscosity of oil, separating the emulsification of oil and water, etc. [1, 2]. According to the analysis of the temperature field of viscous oil, an uneven distribution of the microwave field in the oil tank will cause regional differences in the distribution of the temperature field. From the point of view of analyzing the heat transfer process [3], during microwave heating, oil molecules move rapidly and begin to quickly penetrate other areas. Macroscopically, a hot oil product transfers energy to a region with a lower temperature due to thermal conductivity. At the same time the effect of thermal conductivity is decisive in comparison with natural convection. It was determined [3-5] that microwave energy is intensively absorbed by a viscous petroleum product. Analysis of literature data shows that the method of microwave heating of oil tankers is feasible and it is advisable to study it for further application in industry. However, there is a need to conduct analytical and experimental studies of the process of heating petroleum products in a microwave field to solve certain problems, one of which is the intensification of draining high-viscosity petroleum products from railway tanks.

To describe the heating process of a cylindrical tank with petroleum products exposed to high-frequency electromagnetic radiation, the equation of thermal conductivity in cylindrical coordinates is applied in [6]. The analysis of the work allows us to conclude that the proposed method of mathematical modeling of microwave heating of petroleum products can be taken as a basis. Modeling of microwave heating of high-viscosity petroleum products should be carried out on the basis of the differential equation of thermal conductivity, taking into account internal heat sources. However, it is impossible to use the proposed results directly, since this paper considers the process of heating a large volume, which cannot be described by cylindrical coordinates.

The mathematical model of heating petroleum products in a tank from the action of a microwave source is based on the assumption that heat propagation is carried out in an unlimited array during thermal conductivity under conditions of internal energy sources. Assuming that the thermophysical properties are constant and the power of the microwave field is determined by the action of internal heat sources q_v, the differential equation of thermal conductivity takes the following form:

$$\frac{\partial t}{\partial \tau} = a \nabla^2 t + \frac{q_v}{\rho c_p}, \tag{1}$$

a - is the coefficient of thermal conductivity,

ρ - is the density of the petroleum product,
c_p - is its heat capacity.

The conditions for unambiguity are as follows:
- petroleum product represents an unlimited array;
- the initial temperature distribution of the array is uniform.

The problem was solved in spherical coordinates, for which the Laplace operator ∇^2, provided that the temperature changes only along the radius r, has the following form:

$$\nabla^2 t = \frac{\partial^2 t}{\partial r^2} + \frac{2}{r}\frac{\partial t}{\partial r}, \tag{2}$$

The boundary condition is $\left(\frac{\partial t}{\partial r}\right)_{r=\infty} = 0$, where $r = \sqrt{x^2 + y^2 + z^2}$ (The origin is placed in the volume under consideration).
The finite difference method was used to calculate temperatures.
The following values of physical characteristics were used in the calculations: ρ = 950 kg/m^3, c_p = 3 KJ/(kg·K), L = 300 KJ/kg, λ = 0.125 V/(m·K) [13]. According to [14], for fuel oil, the relative permittivity ε'= 3,5-4,5 and penetration depth tgδ = 0,013-0,03, this is typical for dielectrics, which absorb microwave energy quite efficiently.
In Fig. 1 shows the temperature field in the oil product for different time intervals.

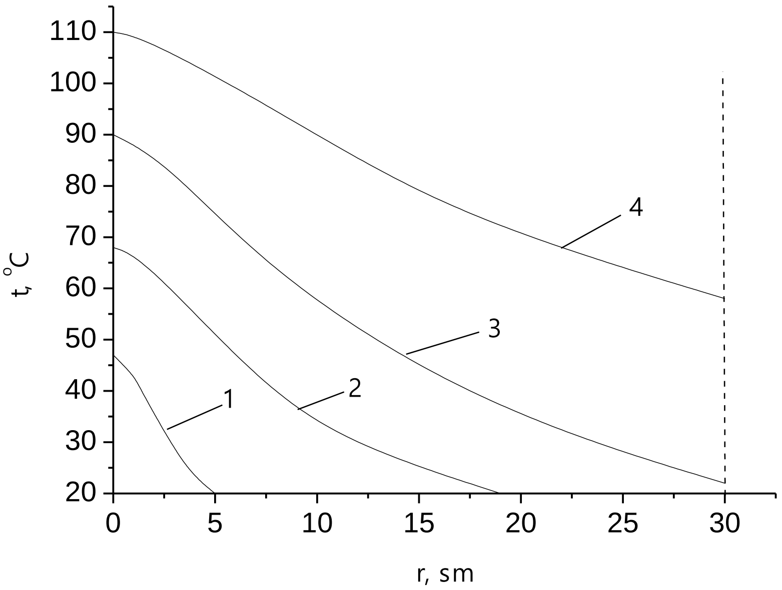

Figure 1. Calculated change in the temperature of fuel oil in the tank during microwave heating
1 - τ = 1 min, 2 - τ = 10 min, 3 - τ = 65 min, 4 - τ = 116 min.

The temperature of fuel oil increases over time, and the front of the heated area expands. After 65 minutes, this front reaches the drain hole, but the oil temperature is insufficient to start the pumping process. From fig. 1 it can be seen that the fuel oil temperature of 60 ºC at the drain hole will be reached in 116 minutes. To increase the flow rate, ensuring that the required temperature is reached at the drain hole of 60 ºC, you can install a magnetron of greater power, for example, 15 kW. Then the consumption will increase to 0.93 kg/s.
When developing a device for microwave heating, the following should be taken into account [7]: the volume of product in tanks can vary widely, and, accordingly, the load resistance (heated

volume) changes, so it becomes necessary to coordinate the latter with the microwave generator in order to avoid damage to the magnetron, which must be reliably protected from load mismatch.

Conclusions

An analytical study of the process of microwave heating of petroleum products is carried out on the example of fuel oil. It is obtained that the temperature of fuel oil increases over time, and the front of the heated region expands. For an initial temperature of 20 ºC after 65 minutes. the hot front reaches the drain hole, but the oil temperature is not sufficient to start the pumping process. Under the specified conditions (initial temperature 20 ºC, magnetron output power 3 kW, relative permittivity ε'= 4.5 and loss angle tangent tgδ = 0.03), the fuel oil temperature of 60 ° C at the drain hole will be reached in 116 minutes. To increase the flow rate, ensuring that the required temperature is reached at the drain hole of 60 ºC, you can install a magnetron of greater power, for example, 15 kW. In this case, the consumption will increase to 0.93 KG/s.

The circuit solution for a microwave device allows you to place the radiation source in close proximity to the drain hole. It is suggested to place the microwave device in a hollow pipe that can be connected to the upper hatch. The microwave energy emitter comes out of the lower base of the pipe and is located directly above the drain at a distance of 1.5 penetration depth. With this location of the source relative to the drain hole, heating, and, accordingly, a decrease in the viscosity of the oil product, will be observed in the drain zone, which can significantly intensify the process and reduce energy costs for heating.

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